flection experiments is much less than the absorption edge energy of 0.12 ev. The two results are not inconsistent, however, since the absorption edge energy is approximately the sum of an energy gap and the Fermi level, ϵ_F.[8] Although our effective-mass data are too limited to permit an accurate calculation of ϵ_F, we obtain a rough estimate of 0.085 ev for ϵ_F by assuming an average value of $m^* = 0.01\, m_0$. The sum of ϵ_F and energy gap is thus about 0.11 ev, in satisfactory agreement with the absorption edge energy.

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EFFECT OF HYDROSTATIC COMPRESSION ON THE ENERGY OF THE 14.4-kev GAMMA RAY FROM Fe^{57} IN IRON*

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The energy of the recoil-free fraction of the γ rays emitted by nuclei bound in solids[1] has been found to be affected by temperature[2,3] and by electronic configuration.[4-7] The latter effect has been named the "isomeric" shift. Compression of a solid should influence the energy through both of these mechanisms. We have measured the effect of hydrostatic compression at 295°K on the energy $h\nu$ of the recoil-free 14.4-kev γ rays emitted by 0.1-μsec Fe^{57} bound in metallic iron. The temperature coefficient of the energy has also been measured more accurately than before.

The apparatus, described in the block diagram of Fig. 1, was that developed for measurement of the effect of gravity,[8] except that an aluminum-windowed proportional counter 60 cm deep having an argon-methane mixture at atmospheric pressure was used. This counter made possible a counting rate up to 2×10^4 per second in the pulse-height channel corresponding to 14.4 kev by virtue

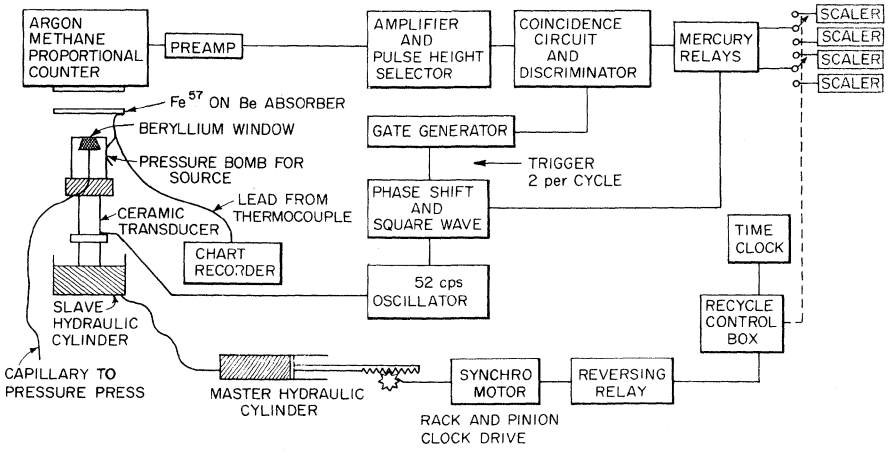

FIG. 1. A block diagram of the apparatus. Alternate five-minute periods automatically record data on separate pairs of scalers, corresponding to upward and downward motion of the hydraulic cylinder. Backlash in the drive is removed during a 30-sec dead time between counting periods.

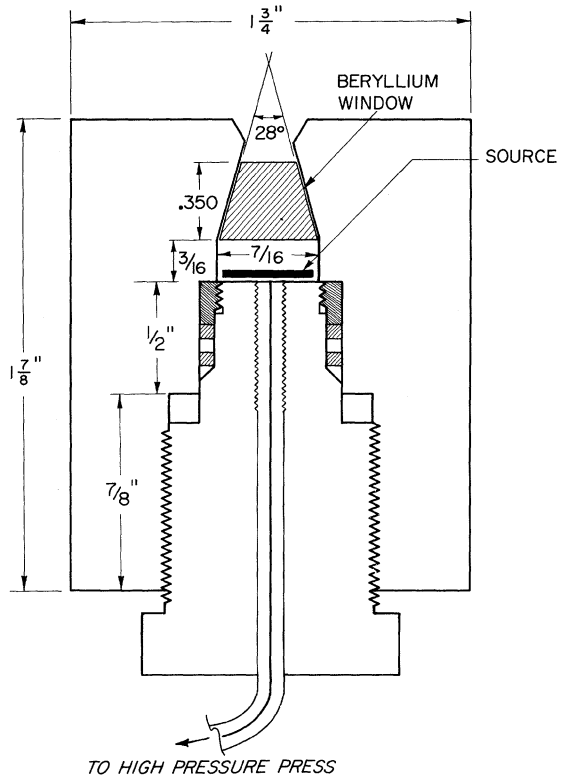

FIG. 2. A cross-sectional drawing of the pressure bomb.

of its small response to the copious initial 120-kev γ ray. The source, about 2 mC of Co^{57} diffused into iron, was enclosed in a beryllium-copper pressure bomb equipped with a one-half-inch thick Be window, as shown in Fig. 2. The bomb was cemented to the ferroelectric transducer and connected to a Bridgman press by a stainless steel tube.

Pressures of one atmosphere, about 2000 kg/cm^2, and 3000 kg/cm^2 were used to determine the pressure coefficient of frequency. The result found was

$$\frac{1}{\nu}\left(\frac{\partial\nu}{\partial P}\right)_T = -(2.61\pm0.10)\times10^{-18} \text{ per kg/cm}^2. \quad (1)$$

The error assigned is double the standard deviation associated with counting statistics to allow liberally for systematic instabilities. It was not convenient to use a "monitor" channel as in the gravitational experiment. A systematic effect attributable to pressure in the bomb and feed tube, which might be thought to change the transducer waveform, was shown to be absent in separate runs that utilized a source mounted on the outside of the bomb.

The temperature coefficient was measured by comparing the apparent shift between source and absorber when they were at nearly equal temperatures with that found when the absorber (enriched Fe^{57} plated on Be backing) was held about 5°C warmer than the source. As in the gravitational experiment, only differences attributable to the parameter changed were significant owing to the presence of shifts of comparable scale inherent in all source-absorber combinations. In both experiments temperature differences were monitored continuously by the recording thermocouple and variations were taken into account. The result found for the temperature coefficient at 297°K and one atmosphere was

$$\frac{1}{\nu}\left(\frac{\partial\nu}{\partial T}\right)_P = -(2.09\pm0.05)\times10^{-15} \text{ per °K}, \quad (2)$$

identical to, but more precise than, the earlier measurement.[2]

We suppose that the temperature coefficient may be split into two parts;

$$\frac{1}{\nu}\left(\frac{\partial\nu}{\partial P}\right)_T = \frac{1}{\nu}\left(\frac{\partial\nu_{\text{isom}}}{\partial \ln V}\right)_T\left(\frac{\partial \ln V}{\partial P}\right)_T + \frac{1}{\nu}\left(\frac{\partial\nu_{\text{rel}}}{\partial \ln V}\right)_T\left(\frac{\partial \ln V}{\partial P}\right)_T. \quad (3)$$

The first term represents the effect of changing the electronic density at the nucleus $|\psi(0)|^2$ and the second the relativistic effect of changing the mean vibrational energy. An estimate of the second contribution may be made from the Debye model which gives, as an approximation, for the vibrational energy;

$$E_{\text{vib}} = 3kT\left[1+\frac{1}{20}\left(\frac{\theta}{T}\right)^2+\cdots\right]. \quad (4)$$

For the Debye temperature θ not much larger than the temperature T, the approximation above is adequate without more terms than written. From this is obtained

$$\frac{1}{\nu}\left(\frac{\partial\nu_{\text{rel}}}{\partial \ln V}\right)_T\left(\frac{\partial \ln V}{\partial P}\right)_T \approx -\frac{3}{20}\frac{k\theta}{Mc^2}\left(\frac{\theta}{T}\right)\left(\frac{\partial \ln\theta}{\partial \ln V}\right)_T\left(\frac{\partial \ln V}{\partial P}\right)_T, \quad (5)$$

where M is the atomic mass of Fe^{57} and Grüneisen's constant γ may be used for $-(\partial \ln\theta/\partial \ln V)_T$. For $\theta\approx400$°K, $\gamma=1.6$,[9] and $(\partial \ln V/\partial P)_T = -5.98\times10^{-7}$ per kg/cm^2,[10] one obtains at $T=295$°K a value for Eq. (5) of approximately -0.126×10^{-18} per kg/cm^2. This is less than 5% of the pressure coefficient

observed. The volume dependence of the isomeric shift must therefore account for the major part of the pressure coefficient. (A related calculation of the effect of pressure on the lattice vibrations and therefore on the amount of the recoil-free fraction has been given by Hanks.[11]) One may also conclude that the net pressure coefficient should vary only weakly with temperature. At $T = 0°K$ the vibrational contribution would be about -0.35×10^{-18} per kg/cm^2. For $T \gg \theta$ this contribution approaches zero. This explicit temperature variation is reduced by the decrease of $(\partial \ln V/\partial P)$ with temperature.

If the pressure coefficient originates mainly in the isomeric shift, one may write

$$\frac{1}{\nu}\left(\frac{\partial\nu}{\partial P}\right)_T \cong \frac{1}{\nu}\left(\frac{\partial\nu_{\text{isom}}}{\partial \ln V}\right)_T \left(\frac{\partial \ln V}{\partial P}\right)_T = K\left(\frac{\partial|\psi(0)|^2}{\partial \ln V}\right)_T \left(\frac{\partial \ln V}{\partial P}\right)_T . \tag{6}$$

The fractional frequency shift per unit change of electronic density K can be estimated from isomeric shifts measured for iron ions of differing configuration provided that differences of the values of $|\psi(0)|^2$ appropriate to those ions can be estimated. This estimation can be made[7] using calculated free-ion wave functions.[12] This procedure gives

$$K \approx -(1.6\pm0.2)\times10^{-12} \text{ per } a_0{}^3, \tag{7}$$

where a_0 is the Bohr radius. Equations (6) and (7) lead to

$$\partial|\psi(0)|^2/\partial \ln V = -(2.7\pm0.4)a_0{}^{-3}. \tag{8}$$

If one were to estimate $\partial|\psi(0)|^2/\partial \ln V$ from the assumptions (1) that only $|\psi_{4S}(0)|^2$ is changed by compressions, and (2) that the $|\psi_{4S}(r)|^2$ scales with the volume, i.e., $(\partial \ln|\psi_{4S}(0)|^2/\partial \ln V) = -1$, then the estimate[7] $|\psi_{4S}(0)|^2 \approx 3a_0{}^{-3}$ gives $(\partial|\psi(0)|^2/\partial \ln V)_{\text{estimated}} = -3a_0{}^{-3}$.

The temperature coefficient of γ-ray energy at constant pressure has two contributions:

$$\frac{1}{\nu}\left(\frac{\partial\nu}{\partial T}\right)_P = \frac{1}{\nu}\left(\frac{\partial\nu}{\partial T}\right)_V + \frac{1}{\nu}\left(\frac{\partial\nu}{\partial P}\right)_T \left(\frac{\partial P}{\partial \ln V}\right)_T \left(\frac{\partial \ln V}{\partial T}\right)_P . \tag{9}$$

The first term is the explicit temperature dependence at constant volume, and the second is the effect of thermal expansion. At 295°K the second term is

$$\frac{1}{\nu}\left(\frac{\partial\nu}{\partial \ln V}\right)_T \left(\frac{\partial \ln V}{\partial T}\right)_P = +(0.15\pm0.01)\times10^{-15} \text{ per } °K, \tag{10}$$

which is opposite in sign to the observed effect of temperature. This, combined with the remeasured temperature coefficient, Eq. (2), gives

$$\frac{1}{\nu}\left(\frac{\partial\nu}{\partial T}\right)_V = -(2.24\pm0.06)\times10^{-15} \text{ per } °K. \tag{11}$$

It is this quantity which should be compared to the effect derivable as a consequence of time dilatation,[2]

$$\left[\frac{1}{\nu}\left(\frac{\partial\nu}{\partial T}\right)_V\right]_{\text{relativistic}} = -C_{LV}/2Mc^2, \tag{12}$$

where C_{LV} is the specific heat at constant volume of only the lattice and M is the atomic mass. Bijl[13] has extracted values for $C_{LV}(T)$ from specific heat data, and gives a value for iron amounting to 0.935 of the classical value at 295°K. He has not corrected for possible contributions to the measured specific heat from spontaneous magnetization. Using the above value, one finds

$$\left[\frac{1}{\nu}\left(\frac{\partial\nu}{\partial T}\right)_V\right]_{\text{relativistic}} \approx -(2.28\times10^{-15}) \text{ per } °K, \tag{13}$$

where an unknown uncertainty should be assigned to allow for magnetic specific heat. The agreement between the values in Eqs. (11) and (13) suggests that at 295°K the isomer shift depends explicitly only weakly on temperature. In contrast Benedek and Armstrong[14] found an explicit temperature dependence of $|\psi_\uparrow(0)|^2 - |\psi_\downarrow(0)|^2$, where $\uparrow$ and $\downarrow$ denote spin orientation, from studies of the nuclear magnetic resonance in iron.

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OBSERVATION OF SOLID-STATE PHOTOEMISSION FROM TIN INTO GERMANIUM

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The process of photoemission of electrons from one solid into another in contact with it has been postulated by several workers. Mott and Gurney[1] suggested the existence of an internal photoelectric effect to explain certain data for sodium metal in contact with rock salt crystals. Gilleo[2] investigated the existence of this effect in more recent work with silver on alkali halide crystals. Most recently, Williams and Bube[3] proposed that photoemission from copper and other metals plated on cadmium sulfide crystals takes place. All the above experiments required relatively energetic radiation (greater than 1 ev) to produce effects.

Recently we observed an extended spectral response for photovoltaic and photoconductive effects in tin-plated germanium. The test specimen was a slice of "*n*"-type 30-ohm-cm germanium 20 mils thick, on opposite faces of which were electroplated tin contacts. The contacts were $\frac{1}{4}$ inch$\times\frac{1}{4}$ inch square and were displaced with respect to one another by $\frac{1}{8}$ inch. In the test setup, radiation from a monochromator was made to pass through the germanium and impinge on the tin metal. The photovoltaic or photoconductive signal across the contacts was measured. The radiation was chopped at 450 cps, and the signal was amplified by a narrow-band ac amplifier. Room-temperature measurements on this and many similar specimens failed to show any extended spectral response. However, at liquid-nitrogen and liquid-helium temperatures, an extended spectral response several hundred times smaller than the peak intrinsic responses was detected.

To ensure that intrinsic excitation processes and short-wavelength scattered light did not produce the observed signals, germanium filters of various thicknesses were interposed in the exit beam of the monochromator. Typical results are illustrated in Fig. 1, which shows that the use of filters differing in thickness by a factor of ten caused no significant decrease in long-wavelength

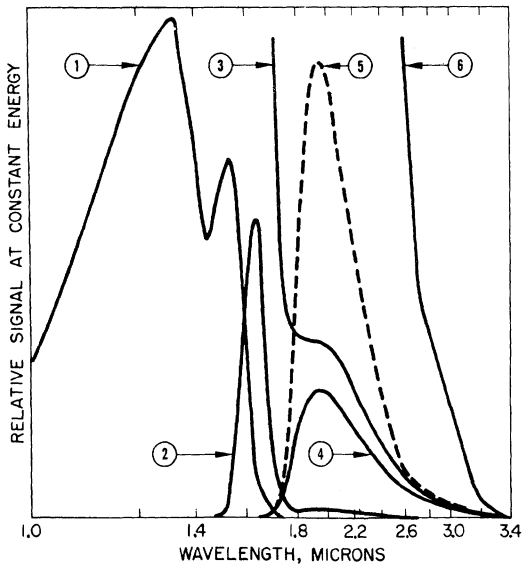

FIG. 1. Photovoltaic signals at constant energy for electroplated tin-on-germanium cell No. 1. Curve 1: the "intrinsic" photovoltaic response with no filtering of the monochromator radiation. Curve 2: radiation is filtered by a 10-mil-thick germanium filter; amplifier gain is ten times that used for curve 1. Curve 3: 10-mil-thick germanium filter is used again, but amplifier gain is ten times that used for curve 2. Curve 4: same gain as that for curve 3, but a 100-mil-thick germanium filter is used. Curves 1 through 4 were taken at liquid-nitrogen temperature. Curve 5: same gain as that for curves 3 and 4, 100-mil-thick filter, but liquid-helium cooled. Curve 6: same conditions as those for curve 5, but amplifier gain increased ten times. The extended spectral response lies at wavelengths greater than 1.8 microns approximately.